Fermi National Accelerator Laboratory

FERMILAB-Conf-92/112-E

Search for the Λ_b Baryon at CDF

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April 1992

Published Proceedings *XXVIIth Rencontres de Moriond, QCD and High Energy Interactions*, Les Arcs, France, March 22-28, 1992.

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CDF/PUB/CDF/PUBLIC/1715
XXVIIth Rencontres de Moriond
Les Arcs (Savoie), France
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Abstract

The Λ_b baryon has been observed recently by UA1 through its decay $\Lambda_b \rightarrow J/\psi\Lambda^0$. Although CDF finds twice as many J/ψ and observes Λ^0 decays, no evidence for a Λ_b signal is seen. The UA1 data supports a lower than expected production P_T for the Λ_b, and therefore, a lower pion P_T, below the observation threshold of CDF. This result suggests that UA1 and CDF are probably not inconsistent, but also that the production models are not quite right.

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1 Introduction

Recently, the UA1 collaboration reported the observation of the Λ_b baryon in high-energy $\bar{p}p$ collisions [1]. Can the CDF experiment confirm this result? We are looking for the decay chain $\Lambda_b \rightarrow \psi\Lambda^0$ with $J/\psi \rightarrow \mu^+\mu^-$ and $\Lambda^0 \rightarrow p\pi^-$ (and charge conjugates).

The advantage with this decay mode of the Λ_b is that it is easy to form an efficient dimuon trigger to record J/ψ events with which we can then look for evidence of the Λ_b. The CDF detector and the dimuon trigger are described elsewhere [2]. Briefly, the trigger consists of two levels. First, the muon slope is measured as a drift time difference between hits in two layers of a muon drift chamber. This slope is related to the P_T of the muon and is used to require two muons above 3 GeV/c. Then, tracks are reconstructed in a tracking chamber (embedded in a 1.5 T B-field) with a hardware track processor. Two of these tracks above 3 GeV/c are required to match with a level 1 muon trigger.

With this trigger, a total of 4.4 pb^{-1} of $\bar{p}p$ collision data was recorded over almost one full year of data-taking in 1988-1989.

2 Mass Distributions for J/ψ, Λ^0, and Λ_b

When combining all opposite-sign pairs of reconstructed muons in the full data sample, a clear J/ψ signal is obtained (see figure 1). The events in the mass window of ± 50 MeV/c^2 around the accepted value [3] are refit to a common vertex *and* the actual J/ψ mass.

Within those events, Λ^0 are searched by considering all pairs of "good" opposite-sign tracks. Here, "good" is taken very loosely in order to maximize the efficiency for finding Λ^0. The criteria is that only one segment is sufficient in both views of the tracking chamber and each segment is only required to have 2/3 of the maximum number of hits. Because most of the Λ^0 momentum is expected to be transferred to the proton, the highest-momentum particle in the pair is taken to be the proton. The two tracks are then fit to a common vertex. This fit gives a χ^2 and a secondary vertex position from which the Λ^0 decay length ($L_{R\phi}$) is computed. Cuts are applied on these two parameters: $\chi^2 > 0.001$ and $L_{R\phi} > 2cm$. The Λ^0 signal is shown on figure 2, again consistent with the approved value [3] and with a very good mass resolution. A cut of ± 4 MeV/c^2 around the peak is applied.

One can then combine the J/ψ and Λ^0 and look for evidence of a signal. At this point, only J/ψ and Λ^0 in the same hemisphere are considered. This rejects background where the Λ^0 is part of the jet recoiling against the J/ψ. The resulting distribution is shown in figure 3. We observe no peak at the location determined by UA1.

3 Monte-Carlo Studies

To quantify the disagreement between UA1 and CDF, it is necessary to use a monte-carlo simulation to determine the efficiency of the reconstruction.

The b quarks were generated with ISAJET with $P_T = [5, 200] GeV/c$ and $\eta = [-1.2, +1.2]$ and then fragmented according to the Peterson model [4]. A simple trigger simulation required that the two muons be above 2.5 GeV/c and in the pseudorapidity range covered by the CDF muon detectors, $[-0.6, +0.6]$. A full detector simulation was performed using realistic tracking inefficiencies based on real J/ψ events. The effect of the underlying events was considered by overlapping the simulated Λ_b data on top of real J/ψ events. Finally, the resulting events were processed through the analysis described above giving an average efficiency of $20 \pm 4\%$ for Λ^0 and $\overline{\Lambda^0}$ (folding in the 64% Λ^0 charged branching ratio).

The expected Λ_b mass resolution is about 20 MeV/c^2 while for the Λ^0, the monte-carlo mass resolution is consistent with the data (respectively 1.8 MeV/c^2 and 1.6 MeV/c^2). Figure 4 shows the expected pion P_T distribution from the Λ^0 decays. It indicates that only Λ^0 which produce pions with P_T above 300 MeV/c can be reconstructed.

4 Limit on $F(\Lambda_b)BR(\Lambda_b \to J/\psi\Lambda^0)$

Based on their observed Λ_b events, UA1 has reported a measurement [1] of the quantity:

$$X = F(\Lambda_b) \cdot BR(\Lambda_b \to J/\psi\Lambda^0) \tag{1}$$

This is the product of the number of b quarks fragmenting to Λ_b times the branching ratio of Λ_b decaying to $J/\psi + \Lambda^0$. It is related to the observed number of events through the equation:

$$N(\Lambda_b) = 2\mathcal{L} \cdot \sigma(b) \cdot \epsilon(J/\psi)\epsilon(\Lambda^0) \cdot X \tag{2}$$

where $\mathcal{L} = 2.6 \pm 0.2$ pb^{-1} is the integrated luminosity of the useable data sample, $\sigma(b) = 6.1 \pm 1.9 \pm 1.5\mu$barn is the b cross-section from the CDF data on $B \to J/\psi K$ [5], and $\epsilon(J/\psi)\epsilon(\Lambda^0) = 0.54 \pm 0.13$. The product of these two efficiencies was determined as one number because the systematic errors on the product are smaller. This error consists of three parts, 1) the simulation error, 2) the effect of the decay model (polarization states of the J/ψ and Λ^0), 3) varying the P_T distribution of the generated b.

Since we see no Λ_b events, we can only put a limit on the quantity X. This is done by counting the maximum number of Λ_b in the (J/ψ Λ^0) mass distributions. $N(\Lambda_b)$ is obtained by counting the entries (N_T) within $\pm 40 MeV/c^2$ mass windows (2σ from the monte-carlo mass resolution) and subtracting the background (B).

$$N_T - B = N_T - 2.0 \pm 0.4 = (17.12 \pm 7.98) \cdot 10^{-3} \cdot X \tag{3}$$

It is then possible to determine the 95% CL limit on the quantity X from the value N_T and considering that the constant relating X and N_T has a gaussian error. For the mass range near the UA1 peak, this gives: $F(\Lambda_b) \cdot BR(\Lambda_b \to J/\psi\Lambda^0) < 0.81 \cdot 10^{-3}$ (95% CL) while UA1 reports $F(\Lambda_b) \cdot BR(\Lambda_b \to J/\psi\Lambda^0) = (1.8 \pm 1.0) \cdot 10^{-3}$.

5 Conclusion

There is a discrepancy between CDF and UA1 because there is no Λ_b peak in the CDF data although it contains twice as many J/ψ events (2990 ± 80 vs 1372 ± 39) as the UA1 data, so one would naively expect twice as many Λ_b as well. More quantitatively, this discrepancy also reflects itself in the measurements of $F(\Lambda_b) \cdot BR(\Lambda_b \to J/\psi\Lambda^0)$.

The most likely explanation is that the Λ_b seen by UA1 are in fact softer than the prediction of the monte-carlo. This results in a very soft P_T distribution for the pions from the Λ^0 decays [6], below the lowest P_T cutoff observable by CDF (see figure 4). UA1 does not have a similar low-P_T cutoff in the pion reconstruction efficiency.

This observation is clearly in disagreement with the predictions from the monte-carlo on which we must rely to determine the Λ^0 reconstruction efficiency and the limit on $F(\Lambda_b) \cdot BR(\Lambda_b \to J/\psi\Lambda^0)$. Using a softer spectrum would lower the Λ^0 efficiency and remove the inconsistency.

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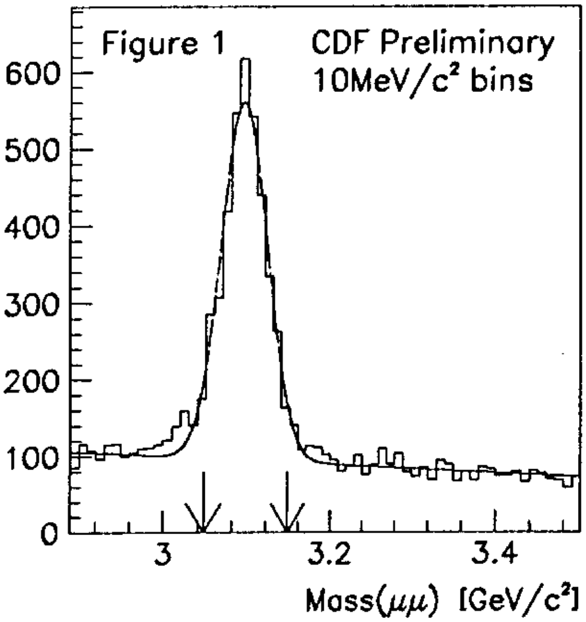

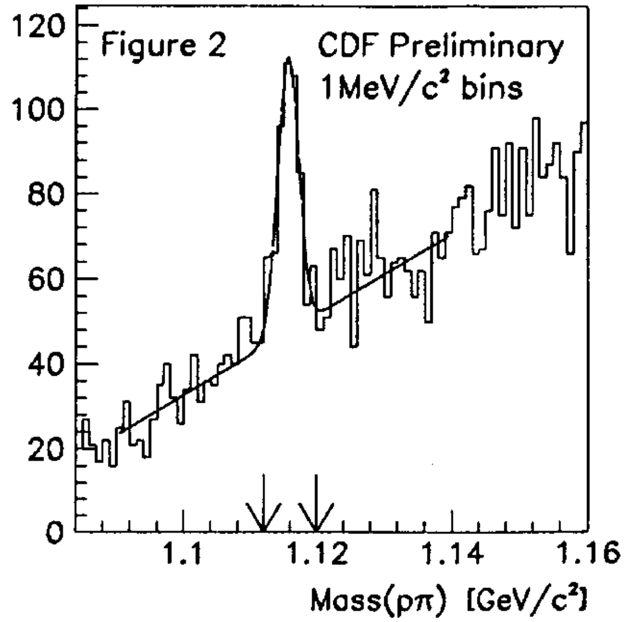

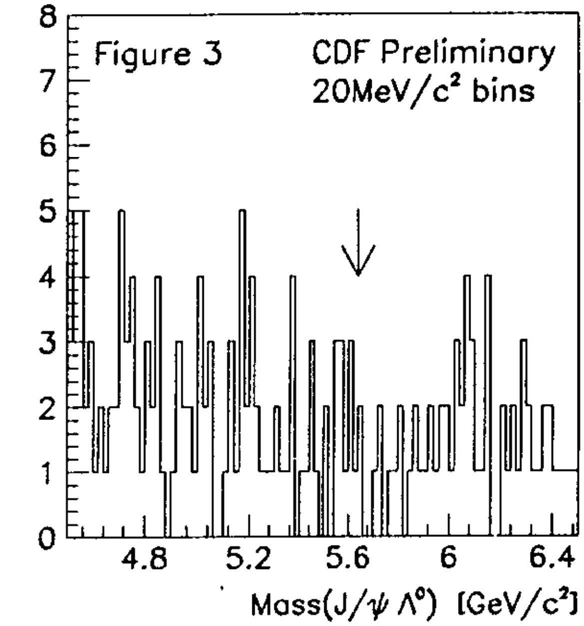

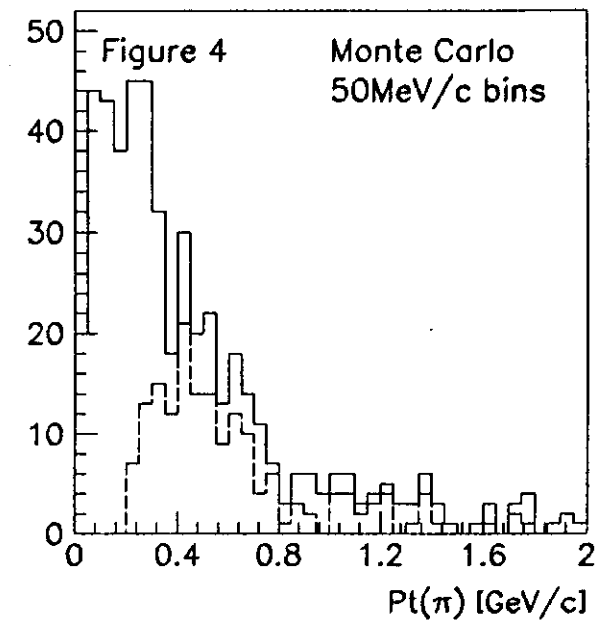

Figure 1 J/ψ signal in $\mu^+\mu^-$ mass combinations. The fitted mass is 3095 ± 1 MeV/c^2 with 2990 ± 80 events above background.

Figure 2 Λ^0 signal in $p\pi^-$ mass combinations. The fitted mass is 1115.6 ± 0.2 MeV/c^2 with 256 ± 30 events above background.

Figure 3 Combination of J/ψ and Λ^0 signals. The arrow indicates the location of the peak for the UA1 observation. *No* Λ_b peak is seen in the CDF data.

Figure 4 The full (upper) curve shows the P_T of the pion from Λ^0 decays in the generated Λ_b events. The dashed (lower) curve shows the same for reconstructed Λ^0.